Controlling Registration in HDI PCBs, *competitively.*

Identifying & Correcting the Specific Causes of Registration Error in High-Density PCBs.

This article deals with the challenge of managing inner layer registration on high-density multilayer PCBs - an issue that most fabricators agree is the largest single obstacle to increasing functional densities. As buried components evolve from basic, passive design to more exotic, even active functions, sub-mil registration tolerances for buried vias will be essential, even on large panel sizes. The common approach of fixing the panel as it moves through production, with various optimization techniques will no longer satisfy these tighter requirements. The level of accuracy required will only be achieved by systematically identifying and correcting the built-in causes of registration failure.

When analyzing registration data on high-density multiplayer PCBs, it is important to remember that all registration error falls into two broad categories:

1. **EXPANSION/SHRINKAGE** - deals with the ***size*** of a particular layer.

Expansion/shrinkage error, sometimes referred to as material movement, is often the largest component of registration error, and usually the easiest, least expensive problem to correct, using corrected scaling data provided by the PerfecTest system.

2. **SHIFT -** deals with the ***x-y position*** of the layers, or ***SHIFT*** and/or ***ROTATION*** of a layer, relative to a given data point. We will refer to this as ***shift error***.

Shift error can be further broken down into two sub-categories:

1.) Random error, caused by non-repeatability of the tooling.
2.) Repetitive, or offset error, caused by incorrect setup.

Random error results from non-repeatability of a process, and can be caused by mechanical problems, such as loose hinges in the artwork imaging machine. Random error can also result from incorrect operator techniques, such as using too much force during stack-up.

There are only three processes in the PCB factory where significant ***shift error*** occurs. The following text and illustrations show where these three types of registration errors occur in the process, and help to identify specific causes of these registration problems.

1. SCALING ARTWORK

ALL ERROR RELATING TO THE SIZE OF A LAYER, OR IMAGE ARE DEALT WITH IN THIS OPERATION

During PCB fabrication, the effects of some processes cause the materials in the panel to become dimensionally unstable, resulting in a layer, or panel that is the incorrect size. We refer to this as **expansion/shrinkage.** The primary causes of this instability are:

1. Stress relief during the mechanical scrubbing or cleaning of the copper surface, prior to dry-film lamination. Chemical cleaning processes have largely eliminated this issue.
2. Additional relief of built-in stresses when copper is removed during the etch cycle.
3. The destabilization of the core and pre-preg materials during the gel phase in the lamination cycle. This 3rd factor is by far the dominant cause of the expansion/shrinkage error problem.

While the materials used in PCB manufacture are typically unstable, the dimensional performance of these materials is very predictable, but ***only if all of the variable factors affecting the stability are known.*** By compensating the size of the artwork, typically called ***scaling***, for the anticipated size changes during fabrication, the size of each layer in the panel can be controlled precisely.

The PerfecTest process measures scaling error, in X and Y axis, for each layer of the panel. This data is then stored according to the specific construction parameters of that panel, as shown in illustration 1. As the database of historical information accumulates, the system software will search the database, find previous jobs with the same construction, &provide the correct scale factor, based on the variables specific to that construction.

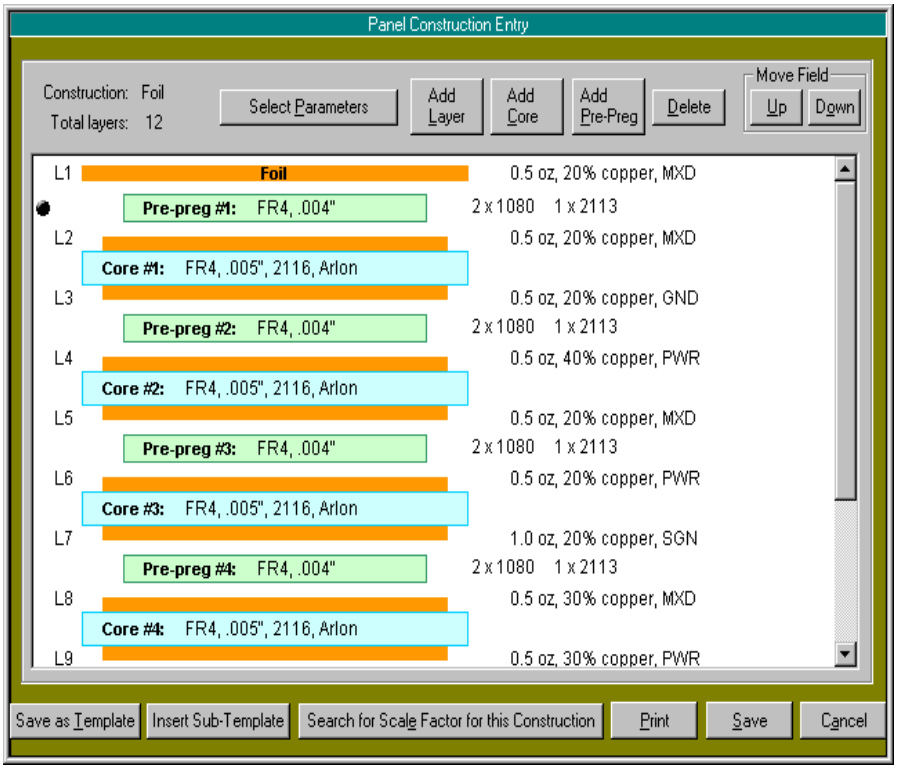


Illustration 1

When panel construction for new jobs is set up in CAM/pre-production, the software program will automatically search the database for previous jobs, ***produced with the same panel construction***, and retrieve a ***material expansion /shrinkage scaling report*** – see illustration 2 at right.

This report will show the scale factor used for each layer on this previous job, the results produced by that scale factor, and the ***corrected scale factor*** for the new job, based on this data.

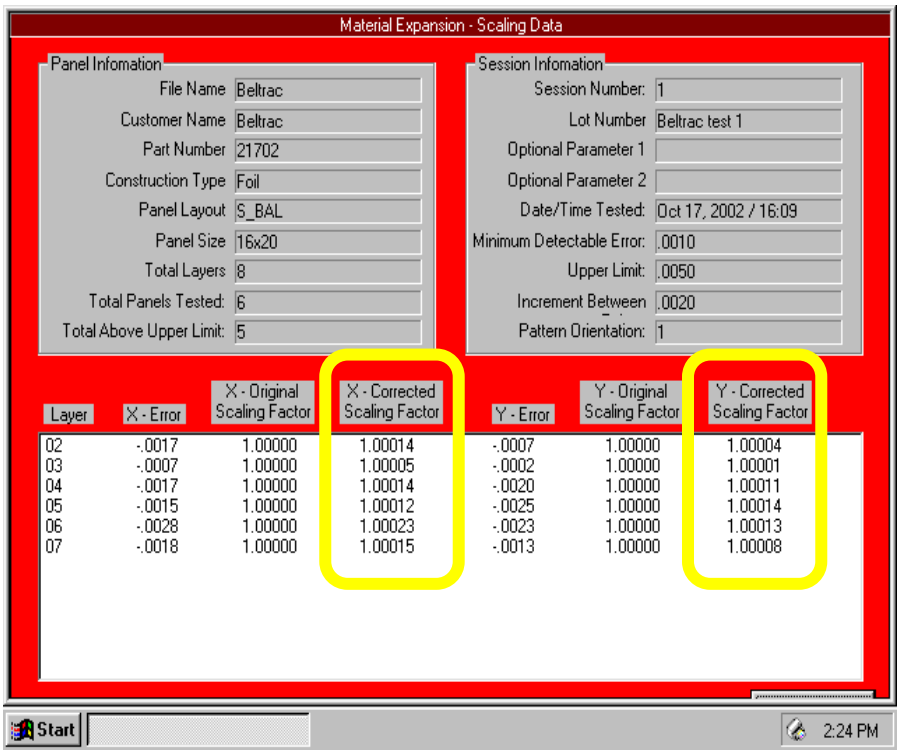


Illustration 2

If there are no previous jobs with exactly the same panel construction in the database, the program will find the closest, or ***best-matching*** jobs, using weighted-value search parameters. The report will indicate the differences, compared to the current job, and provide the ***best-match*** scale factors. As more data is collected over time, scaling targets become tighter, and scaling error is eliminated as a factor in multi-layer registration.

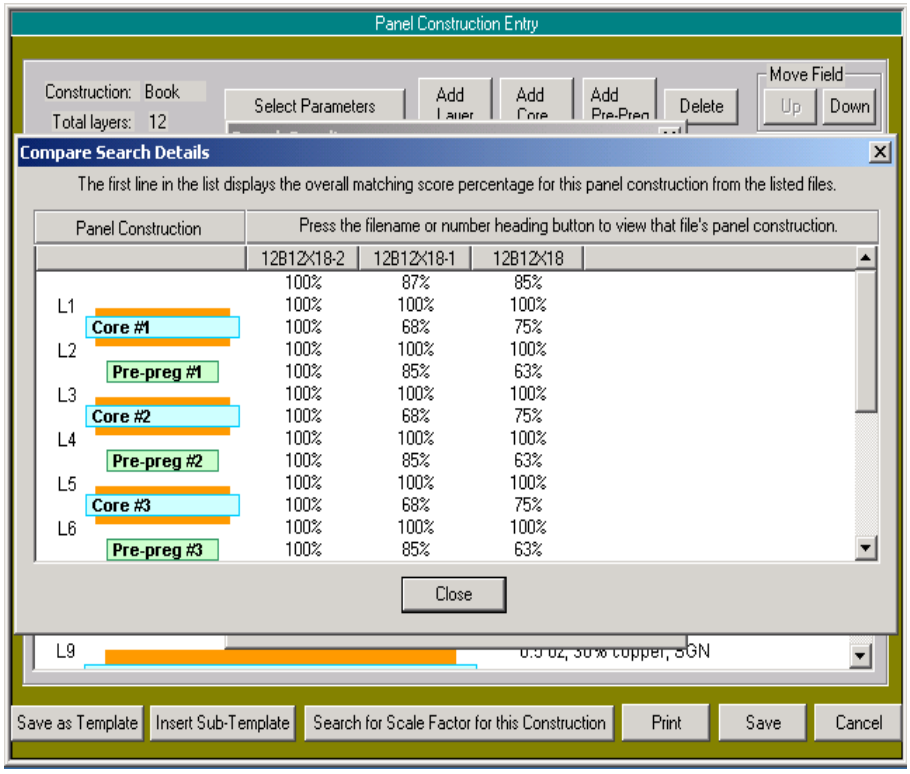


Illustration 3

2. DRY-FILM IMAGING

ALL FRONT-TO-BACK REGISTRATION ERROR OCCURS IN THIS OPERATION

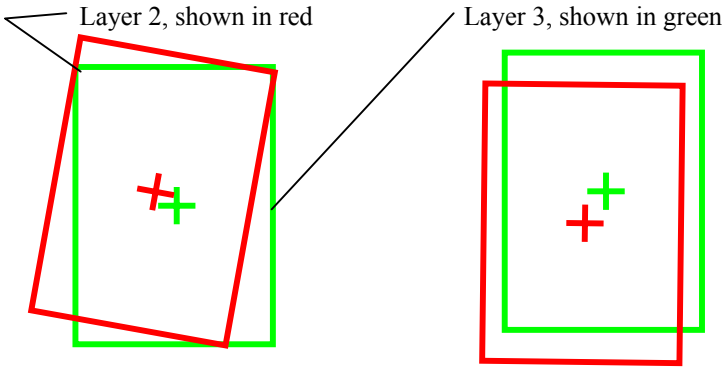


Illustration 1 Illustration 2

In both illustrations at left, there is a ***front-to-back registration shift error***. This shift error can only occur during dry-film imaging of these inner layer cores. When the dry-film imaging process is completed, the position/relationship between layers 2 & 3 is permanently fixed.

All front-to-back registration problems occur during the dry-film imaging process. When analyzing front-to-back registration, look for the cause and solution only in this section – front-to-back shift errors are not significantly affected by processes outside of this section.

When front-to-back error is ***repeated***, from one core to the next, the mechanical registration process is functioning predictably & reliably. The error is the result of incorrectly setting up the artworks in the imaging machines.

Solution: Analyze the mechanisms in imaging that control the location/position of the artwork, relative to the two sides of the core. Determine what action is needed to correct this side-to-side (front-to-back) alignment in the imaging process, then correct the cause of the problem. Depending on the process used in any particular imaging equipment, repetitive error may be caused by:

- Incorrect placement of punch targets on artwork.
- Corrupted camera targets/punch targets on artwork.
- Mechanical non-repeatability of artwork punch.
- Incorrect set-up of artwork in frame.

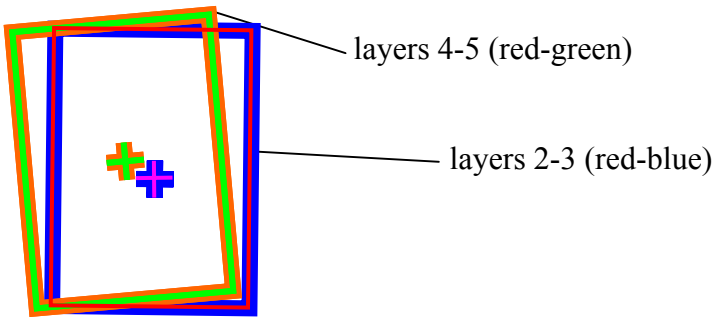
When front-to-back error occurs ***randomly***, the process itself is not able to repeat itself.

Solution: Analyze the mechanisms in imaging that controls the location/position of the artwork, relative to the two sides of the core. Look for:

- mechanical looseness or wear in the hinges of the exposure frame
- worn pins or alignment devices, or the failure of any mechanism that is intended to assure repeatability in the process.

3. LAMINATION

ALL CORE-TO-CORE REGISTRATION ERROR OCCURS IN THIS OPERATION



The illustration at left represents a panel construction where there is ***core-to-core shift error.*** This shift error can only occur during the core-to-core lamination process. After lamination, the positional relationship between the cores is permanently fixed.

All core-to-core registration problems occur during the lamination process. When analyzing core-to-core registration, look for the mechanisms that control the core-to-core alignment during lamination. Core-to-core shift errors are not significantly affected by processes outside of this section.

When core-to-core error is ***repeated*** from one panel to the next, the mechanical processes in this section are functioning predictably & reliably. The error is the result of incorrectly aligning and holding the individual cores while they are being laminated.

Solution: Analyze the processes & mechanisms that position & control the alignment of the cores, relative to the other cores in the panel, during the set-up and lamination process. Depending on the process used during this operation, ***repetitive error*** may be caused by:

- Defective, or incorrectly placed post-etch punch target on the artwork or core.
- Cores are being punched on more than one post-etch punch, with different results

When core-to-core error varies ***randomly*** from one panel to the next, the process is not able to repeat itself.

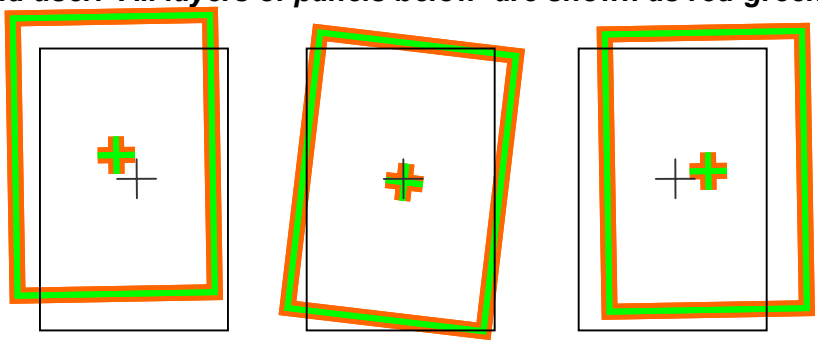
Solution: Analyze the mechanisms that control the location/position of the cores, relative to the other cores, during the lamination process. Look for:

- Mechanical non-repeatability of the post-etch punch.
- Randomly defective post etch punch targets on the core.
- Too much force used during stack-up, which may tear or distort the holes or slots in the cores.
- Loose or damaged pins or rivets used to hold the cores in position during lamination.
- Inadequate alignment technique used to align and/or hold the cores during the riveting or resin welding process.

4. DRILLING

ALL PANEL-TO-PANEL REGISTRATION ERROR OCCURS IN THIS OPERATION

When analyzing panel-to-panel registration, look for the mechanisms that control the core-to-core alignment during drilling. Panel-to-panel shift errors are not significantly affected by processes outside of this section. It is particularly importamt to recognize the substantial errors contributed by the drilling process, and "step drilling" is increasingly discouraged by the end user. All layers of panels below are shown as red-green.



Panel 1 Panel 2 Panel 3

Black outline indicates correct, or nominal position.

Illustrations indicate ***random, panel-to-panel shift error*** at the drill.

To identify specific causes, using a DESIGN OF EXPERIMENT (DOE), mark each stack of panels according to the *spindle* of the *specific drill machine* where they were drilled.

(Example: drill machine #4, spindle #2, top panel, middle panel, bottom panel. The panels can be marked or coded as D4-S2,T,M,B.) If PerfecTest data indicates a consistent, repetitive offset error, as shown in illustration 1, look for:

- a problem with the zero reference for that particular spindle.
- error in the '0' reference of the tooling device used to create the hole locations that pin the panels at the drill. (post-lamination x-ray drill – "optimizer")
- targets used by the optimizer are incorrectly located, possibly in CAM or at the plotter.

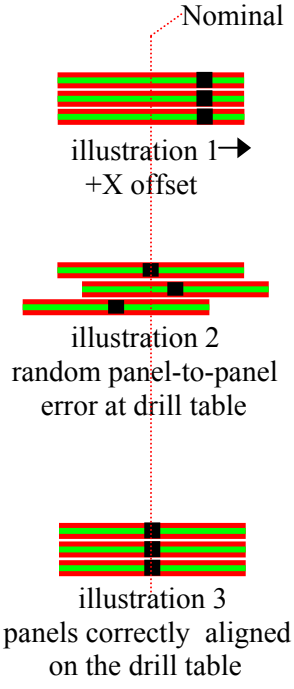


illustration 1→
+X offset

illustration 2
random panel-to-panel
error at drill table

illustration 3
panels correctly aligned
on the drill table

If each of the three panels in the stack has a different '0' offset error, as in illustration 2, the cause lies with the non-repeatablity of the tooling holes used to locate the panels at the drill, or possibly to much force used to press the panels onto the tooling pins of the drill table. The later is common when the slots used during lamination are also used to locate panels on the drill table.

By marking layers, cores, and panels in a DOE with production panels, the engineer is able to use PerfecTest data to attribute specific causes of registration shift error. With precise, reliable data, sound decisions can be made on where to focus efforts and resources, and to to proritize improvements to the process, often by simply calibrating those processes or equipment at minimal cost.

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